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Ant algorithms with immigrants schemes for the dynamic vehicle routing problem

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ABSTRACT

Many real-world optimization problems are subject to dynamic environments that require an optimization algorithm to track the optimum during changes. Ant colony optimization (ACO) algorithms have proved to be powerful methods to address combinatorial dynamic optimization problems (DOPs), once they are enhanced properly. The integration of ACO algorithms with immigrants schemes showed promising performance on different DOPs. The principle of immigrants schemes is to introduce new solutions (called immigrants) and replace a small portion in the current population. In this paper, immigrants schemes are specifically designed for the dynamic vehicle routing problem (DVRP). Three immigrants schemes are investigated: random, elitism- and memory-based. Their difference relies on the way immigrants are generated, e.g., in random immigrants they are generated randomly whereas in elitism- and memory-based the best solution from previous environments is retrieved as the base to generate immigrants. Random immigrants aim to maintain the population diversity in order to avoid premature convergence. Elitism- and memory-based immigrants aim to maintain the population diversity and transfer knowledge from previous environments, simultaneously, to enhance the adaptation capabilities. The experiments are based on a series of systematically constructed DVRP test cases, generated from a general dynamic benchmark generator, to compare and benchmark the proposed ACO algorithms integrated with immigrants schemes with other peer ACO algorithms. Sensitivity analysis regarding some key parameters of the proposed algorithms is also carried out. The experimental results show that the performance of ACO algorithms depends on the properties of DVRPs and that immigrants schemes improve the performance of ACO in tackling DVRPs.

1. Introduction

Ant colony optimization (ACO) algorithms have been successfully applied for solving different combinatorial optimization problems, e.g., vehicle routing problems (VRPs) [12,15]. Traditionally, researchers have drawn their attention on stationary optimization problems, where the environment remains fixed during the execution of an algorithm [23,48]. However, many real-world applications are subject to dynamic environments. Dynamic optimization problems (DOPs) are challenging since

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the aim of an algorithm is not only to find the optimum of the problem quickly, but to efficiently track the moving optimum when changes occur [29]. A dynamic change in a DOP may involve factors like the objective function, input variables, problem instance, constraints, and so on.

Conventional ACO algorithms have been designed for stationary optimization problems [14], e.g., to converge fast into the global (or near) optimum solution, and may face a serious challenge to tackle DOPs. This is because the pheromone trails of the previous environment may bias the population to search into the old optimum, making it difficult to track the moving optimum. As a result, ACO will not adapt well once the population converges into an optimum. Considering that DOPs can be taken as a series of stationary problem instances, a simple way to tackle them is to re-initialize the pheromone trails and consider every dynamic change as the arrival of a new problem instance which needs to be solved from scratch [37]. However, this restart strategy is generally not efficient.

In contrast, once ACO algorithms are enhanced properly, they are able to adapt to dynamic changes since they are inspired from nature, which is a continuously changing process [2,3,29]. Recently, ACO algorithms have been successfully applied in combinatorial optimization problems with dynamic environments since they are able to reuse knowledge from previously generated pheromone trails [25,26,38]. More precisely, when the changing environments are similar, the pheromone trails of the previous environment may provide knowledge to speed up the optimization process to the new environment. However, the algorithm needs to be flexible enough to accept the knowledge transferred from the pheromone trails, or eliminate older unused pheromone trails, to better adapt to the new environment.

Several strategies have been proposed and integrated with ACO to shorten the re-optimization time and maintain a high quality of the output efficiently, simultaneously. These strategies can be categorized as: increasing diversity after a dynamic change [25,37]; maintaining diversity during the execution [16,38]; memory-based schemes [26,27,36]; and hybrid/memetic algorithms [39].

Among these strategies, immigrants schemes have shown promising results on binary DOPs [55,61], dynamic traveling salesman problems [38], and recently dynamic vehicle routing problems (DVRPs) [35,36]. Within immigrants schemes, a small portion of newly generated ants, called immigrant ants, replace the worst ants in the current population. Each immigrants scheme differs in the way immigrant ants are generated, e.g., random immigrants represent random solutions of the problem [24], elitism- or memory-based immigrants represent solutions that differ slightly from the best solution of a previous environment [54,55]. In this paper, we focus on the immigrants schemes for the DVRP, and thus, the immigrant ants represent a feasible VRP solution.

Random immigrants ACO (RIACO) and elitism-based immigrants ACO (EIACO) [35] were previously applied only on a DVRP where the pattern of dynamic changes is random, denoted as *random DVRPs*, whereas memory-based immigrants ACO (MIACO) [36] was applied only on a DVRP where the pattern of dynamic changes is cyclic, denoted as *cyclic DVRPs*. However, these algorithms were extended from the previous developments proposed for dynamic traveling salesman problems [38], and thus, their behavior was unexpected in most dynamic test cases. In this paper, RIACO, EIACO, and MIACO are redesigned specifically for the DVRP and their performance is investigated on both random and cyclic DVRPs generated by a different benchmark generator. The proposed algorithms differ from their previous versions [35,36] as follows: (1) the way random, elitism- and memory-based immigrant ants are generated; (2) the selection of ant as the base to generate elitism-based immigrants; and (3) the ants selected to replace other ants in the memory in order to generate memory-based immigrants.

The main issue with different dynamic benchmark generators for the DVRP currently used in the literature [30,35,36,41] is that the optimum value is not known during the dynamic changes. The same case stands for the DVRPs considered on the initial developments of RIACO, EIACO and MIACO [35,36]. Therefore, it is impossible to observe how close to the optimum each algorithm converges after a change. In binary and continuous optimization functions, algorithms are benchmarked in dynamic generators where the optimum value is known during the dynamic changes [5,32,53,56]. Comprehensive surveys regarding benchmark generators for DOPs are available in [9,42]. In this paper, the dynamic benchmark generator for permutation problems (DBGP) [40] is mainly used which can generate DVRPs with known optimum over the environmental changes and hence facilitate the observation on how close to the optimum an algorithm performs. Based on the DVRPs generated from DBGP, this paper benchmarks and compares the performance of the re-designed algorithms with other peer ACO algorithms. In addition, the algorithms are compared on the DVRP with traffic factors [38], which models a real-world scenario.

To summarize, the contributions of the paper are as follows: (1) RIACO, EIACO and MIACO, which were developed previously, are re-designed specifically to address the DVRP; (2) the dynamic test cases are generated from the recently proposed DBGP [40]; and (3) the experimental studies are extended on both random and cyclic DVRPs for all ACO algorithms. Sensitivity analysis on key parameters of the algorithms is also carried out.

The rest of the paper is organized as follows. Section 2 describes the basic VRP and its stationary and dynamic extensions. Section 3 briefly reviews existing work on ACO for DVRPs. Section 4 describes the benchmark generator used which can generate DVRPs where the optimum value is known over dynamic changes. Section 5 describes the algorithms proposed in this paper for addressing the DVRP. Section 6 gives the experimental results, including the statistical tests, and analysis. Finally, Section 7 concludes this paper with discussions on relevant future work.